Experimental Study of an SWH System with V-Shaped Plate

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Abstract. Solar energy is known as an environmentally friendly energy source with a wide range of applications. This energy can be utilized in various applications such as domestic and industrial water heating using solar water heating (SWH) systems. The thermal performance of an SWH system using a V-shaped absorber plate is presented in this study. Two SWH systems with different absorber plates, i.e. a flat-plate and a V-shaped plate, have been investigated experimentally. First, the absorptivity of the absorber plates was calculated analytically. The optimum V-shaped configuration with angle at β = 21° (V-shaped dimensions t = 4 cm and l = 4 cm) was determined from various V-shaped plate absorbers based on their absorptivity and applied in the experimental study. Two SWH systems were installed and tested at a low flowrate of 0.5 L/min and at a high flowrate of 2 L/min. The results showed that the SWH system with V-shaped plate absorber had a 3.6-4.4% better performance compared with that of the system with flat-plate absorber.

Keywords: *experimental study; flat-plate absorber; solar water heater; thermal performance; V-shaped plate absorber.*

1 Introduction

Solar energy is a renewable energy source with a wide range of applications such as domestic and industrial water heating, refrigeration, cooking, power production, water pumping, etc. Solar energy devices are increasingly used in green building applications due to their nonpolluting and renewable qualities [1]. Solar water heating (SWH) systems are now widely used in the domestic as well as in the industrial sector due to their ease of operation and simple maintenance. SWH has proven to be an effective technology for converting solar energy into thermal energy. Mumma [2] investigated a solar thermal domestic water heater 28 years ago and concluded that solar thermal domestic hot water offers a wonderful opportunity for energy cost reduction.

The further development of various system components, including the collector, storage tank and heat exchanger, is a subject of interest for enhancing the

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thermal performance of SWH systems. A number of techniques to enhance thermal efficiency in SWH systems have been reviewed by Jaisankar, *et al.* [3]. The efficiency of solar thermal conversion is around 70% when compared to the direct solar electrical conversion system, which has an efficiency of only 17%. A summary of the development of various system components, including the collector, storage tank and heat exchanger, is discussed by Shukla, *et al.* [4]. Ayompe and Duffy [5] have investigated the thermal performance of an SWH system with 4 m^2 flat-plate collectors in Dublin, Ireland. The results showed that the annual average solar fraction, collector efficiency and system efficiency were 32.2%, 45.6% and 37.8% respectively.

Analytical models have been proposed by Subiantoro and Tiow [6] to predict the heat loss from the top cover of single and double glazing flat-plate solar collectors. The energy and exergy efficiency of flat-plate solar collectors was investigated by Jafarkazemi and Ahmadifard [7]. The results showed that designing the system with inlet water temperature at approximately 40 °C higher than the ambient temperature as well as a lower flow rate enhances overall performance. Deng, *et al.* [8] have investigated a novel flat-plate solar collector with micro-channel heat pipe array (MHPA-FPC). Their study demonstrated that the novel MHPA-FPC was a top-level solar collector among current SWH products. In addition, a number of researchers have studied modification of the absorber plate of the solar collector. Integrating the solar absorber with an easily fabricated V-trough reflector can improve the performance of the SWH system. Optical analysis, experimental study and cost analysis of the stationary V-trough SWH system have been studied by Chong, *et al.* [9]. They proposed a stationary V-trough SWH system with a maximum solar concentration ratio of 1.8 suns to improve thermal efficiency. Using chevron type corrugated plates normally used in plate heat exchangers as a plate solar collector was investigated by Dovic and Andrassy [10]. Five different absorber surfaces of the air heater were investigated by Benli [11]. The results showed that the efficiency of the air collector increased depending on the surface geometry of the absorber. The air collector with a corrugated absorber plate had a higher efficiency than the others. A corrugated absorber surface applied in an integrated solar water heater was studied by Kumar and Rosen [12]. The corrugated absorber surface had a significant advantage over a plane absorber surface.

From the studies discussed previously, it can be concluded that the surface geometry of the absorber plate contributes significantly to the performance of the solar collector. Corrugated absorber plates used in the air collector [11] or integrated solar water heater [12] provide a good performance. This indicates that the energy absorbed by the corrugated plate is high compared with a flat plate. Applying a corrugated absorber plate instead of a flat-plate absorber with water tube in a conventional SWH is an attractive topic in this field. A V-shaped absorber plate may provide a better absorptivity not only in the day time but also in the morning and afternoon.

In this study a V-shaped absorber plate was developed and installed in an SWH system. The absorptivity of the V-shaped plate was investigated to obtain the optimal design of the V-shaped configuration. Two SWH systems with different absorber plates, i.e. a flat plate and a V-shaped plate, were built and their performances were investigated experimentally.

2 Solar Water Heating System

The solar water heating system, whose components include the collector, storage tank and heat exchanger, converts solar energy into thermal energy. Solar radiation is absorbed by a collector plate and transferred to water. The hot water produced by an SWH system can be used for supplying hot water in residential, commercial and industrial buildings. The system's performance is affected by the absorber plate and its design, selective coating, thermal insulation, tilt angle of the collector, and working fluid. A schematic layout of a typical thermosyphon solar water heater is shown in Figure 1.

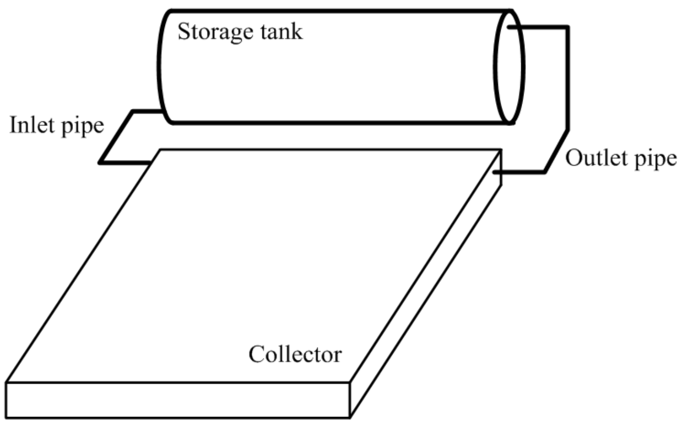
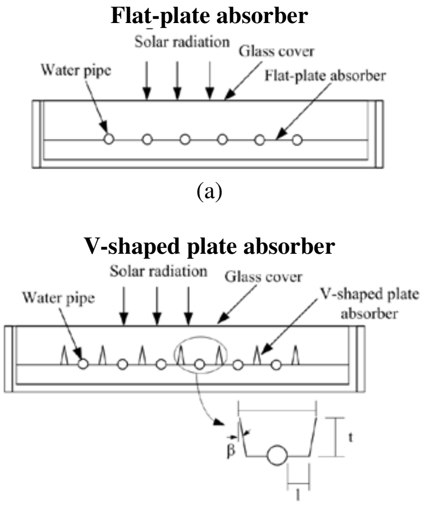


Figure 1 Schematic layout of a typical thermosyphon solar water heater.

Modification of the absorber plate by using a V-shaped absorber plate in the SWH system was conducted in this study. The design of the absorber plate contributes to the performance of the solar collector. A cross sectional view of solar collectors with a flat-plate absorber and with a V-shaped plate absorber are shown in Figures 2(a) and (b) respectively.



(b)

Figure 2 Cross sectional view of solar water heater.

3 Absorptivity of V-shaped Plate Absorber

Two types of plate absorbers, i.e. a flat-plate and a V-shaped plate absorber, were investigated to study the absorptivity of the absorber plates. Increasing the absorptivity of the absorber plate leads to an enhancement of the collector's efficiency. The solar radiation is converted to useful energy by absorbing it in the absorber plate and transferring it to the working fluid. An analytical method was applied to calculate the absorptivity of the flat absorber plate and various types of V-shaped absorber plates. As an example, a cross-sectional view of the ray-tracing result of one of the V-shaped absorber plate is shown in Figure 3.

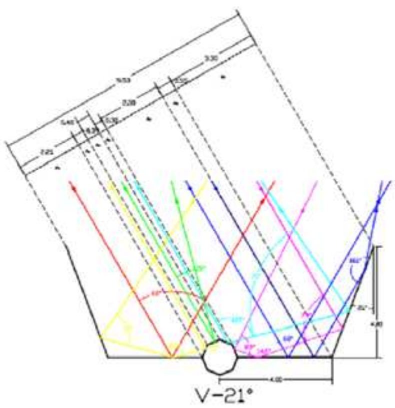


Figure 3 Cross-sectional view of ray-tracing result of V-shaped absorber plate with β = 21° and Θ = 30°.

Solar radiation with incident angle at Θ = 0°, 30°, 60° arrives at the surface of the absorber plate. It arrives at the absorber plate perpendicular (Θ = 0°) in the daytime and at Θ = 60° in the morning and afternoon. The absorptivity of the absorber plate can be calculated based on its incident angle. The absorber plate is assumed to have a black surface. In the case of a V-shaped plate, the solar radiation is reflected several times. The solar radiation is absorbed by the plate with each reflection based on its incident angle.

The absorptivity of a black flat plate with various incident angles presented in ASHRAE [1] was used as reference. Furthermore, the absorptivity of the flat-plate and the V-shaped absorber plates were calculated analytically as listed in Table 1. Increasing the incident angle decreases the absorptivity of the flat-plate absorber. However, the absorptivity of the V-shaped absorber plates increases slightly with an increasing incident angle. This indicates that V-shaped absorber plates provide a better absorptivity compared with a flat-plate absorber plate. The multiple reflections of the solar radiation on the V-shaped absorber plates increase its absorptivity.

Table 1 Absortivity of flat-plate and V-shaped absorber plates.

No.	**Absorber plate orientation**	**Incident angle (Θ)**	**Absorptivity (α)**	**Average absorptivity ($\alpha_{average}$)**	**V-shaped dimension (t and l), cm**
1.	Flat-plate absorber	0	0.963	0.936	-
		30	0.951		
		60	0.894		
2.	V-shaped β = 41°	0	0.985	0.971	4 and 2
		30	0.968		
		60	0.961		
3.	V-shaped β = 32°	0	0.980	0.973	4 and 3
		30	0.974		
		60	0.963		
4.	V-shaped β = 21°	0	0.970	0.975	4 and 4
		30	0.973		
		60	0.981		
5.	V-shaped β = 49°	0	0.966	0.965	3 and 2
		30	0.966		
		60	0.963		
6.	V-shaped β = 40°	0	0.979	0.968	3 and 3
		30	0.960		
		60	0.966		
7.	V-shaped β = 27°	0	0.970	0.970	3 and 4
		30	0.968		
		60	0.970		

Based on the average absorptivity of the V-shaped absorber plates, the optimal design was found to be the V-shaped absorber plate with an angle of β = 21° (V-shaped dimension t = 4 cm and l = 4 cm) as shown in Figure 4. This type of V-shaped absorber plate was applied in an SWH with V-shaped absorber plate in the experimental set-up.

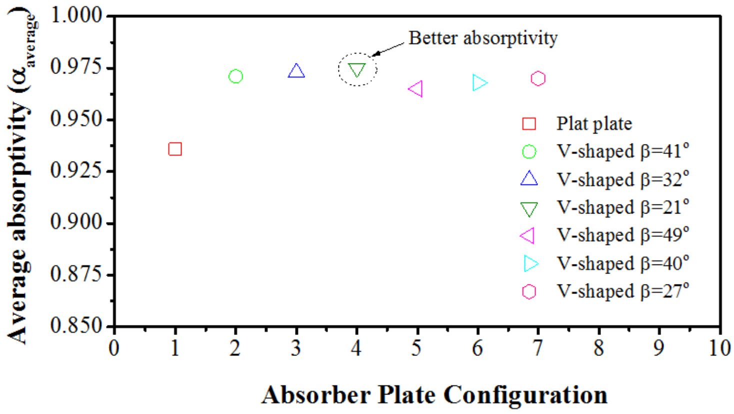


Figure 4 Average absorptivity of absorber plates.

4 Experimental Set-up

Two SWH systems, i.e. one with a flat-plate absorber and one with a V-shaped plate absorber, were installed as shown in Figure 5. Experimental study of both systems was carried out at the Renewable Energy Laboratory, Mechanical Engineering Department of Hasanuddin University Makassar (5° 7' 59" S / 119° 29' 16" E).

The performance of the SWH systems was investigated by calculating the collector efficiency by comparing the useful energy through hot water with the available solar radiation. Useful energy Q_u was calculated based on the recorded data of inlet and outlet water temperature at a certain flowrate, as shown in Eq. (1):

$$Q_u = \dot{m} c_p \Delta T \tag{1}$$

where $\dot{m}$ is flowrate (kg/s), c_p is specific heat (J/kgK) and ΔT is temperature difference of inlet and outlet of water (°C).

Collector efficiency η is defined in Eq. (2) as follows:

$$\eta = \frac{Q_u}{I_T A_c} \tag{2}$$

where I_T is solar radiation (W/m^2) and A_c is collector surface area (m^2).

Experimental study of both SWH systems, i.e. using a flat-plate and a V-shaped absorber plate, was carried out under the same climate conditions. The collector dimensions were 163 cm length and 100 cm width. Water flowed through a copper tube with 0.017 m inner diameter at two different flowrates, i.e. 0.5 L/min (low flowrate) and 2 L/min (high flowrate). Data were recorded in 5-minute intervals from 09.00 until 15.00 o'clock local time.

(a) (b)

Figure 5 Solar water heating system with (a) flat-plate absorber plate(b) V-shaped absorber plate.

5 Results and Discussion

The experimental data were evaluated for the same solar radiation at the same time of day. Figure 6 shows the solar radiation values from the experimental study. The minimum value of the solar radiation occurred in the morning and afternoon. The maximum value occurred in the daytime. Maximum solar radiation was 944.1 W/m^2 at 11:30 local time (August 6, 2015) and 942 W/m^2 at 11:25 local time (August 8, 2015).

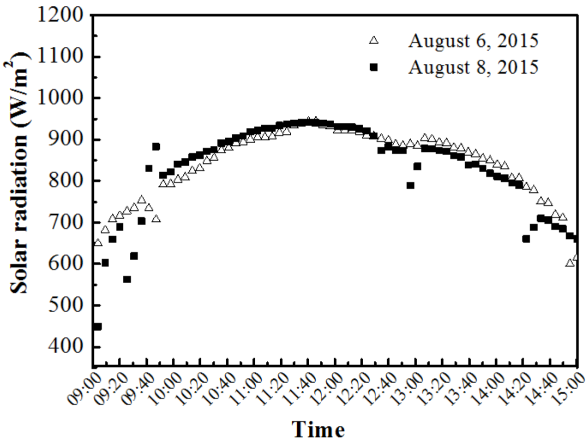


Figure 6 Solar radiation.

Figure 7 shows inlet and outlet water temperature and ambient air temperature. The water flow in both SWH systems was circulated from the same reservoir at the same temperature. The inlet water temperature increased with operating time because the exit water from the collector was recirculated into the reservoir. The outlet water temperature of the collector with V-shaped plate absorber was higher than that of the collector with flat-plate absorber.

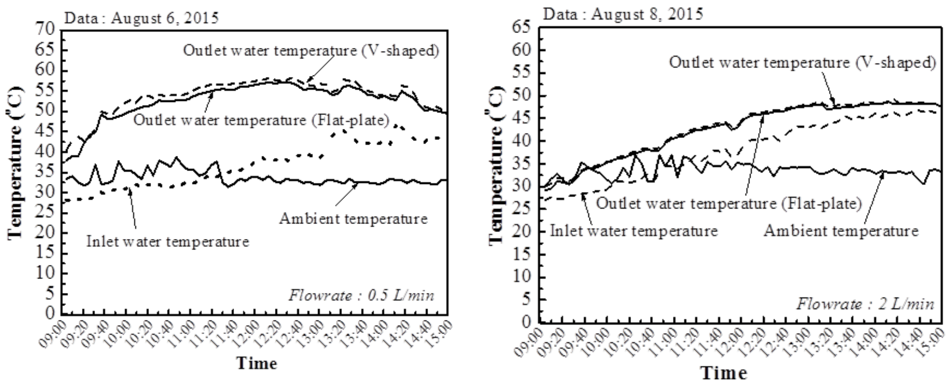


Figure 7 Inlet and outlet water temperature.

Absorber plate temperatures were measured at the plate (T_{plate}) and the pipe surface ($T_{p\text{-}pipe}$), as shown in Figure 5. The recorded temperature data are shown in Figure 8. The temperatures of the V-shaped plate absorber were higher compared with those of the flat-plate absorber. This shows that the absorptivity of the V-shaped plate absorber is better than that of the flat-plate absorber.

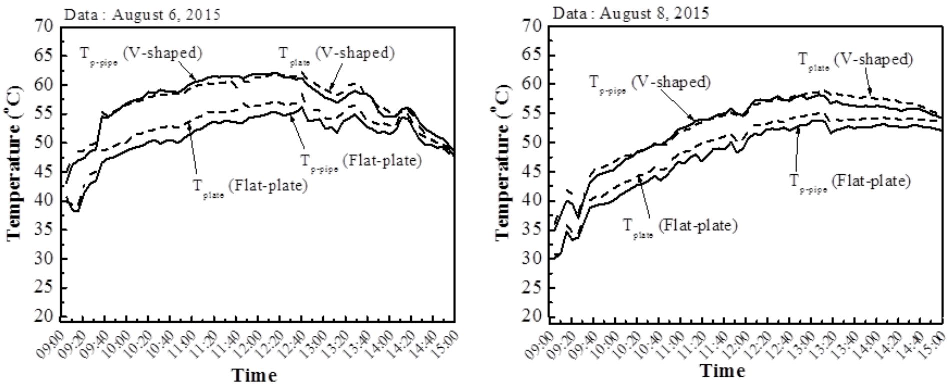


Figure 8 Surface temperature of the absorber plate.

The performance of the SWH system was expressed by collector efficiency. The collector efficiencies of the SWH systems with flat-plate and V-shaped absorber plate are shown in Figure 9. The collector efficiency tended to decrease with operating time. Increasing the inlet water temperature of the collector over the operating time decreased collector efficiency. At the low flowrate, the average daily collector efficiency was 39.8% for the SWH with flat-plate absorber and 43.4% for the SWH with V-shaped plate absorber. At the high flowrate, the average daily collector efficiency was 41.9% for the SWH with flat-plate absorber and 46.3% for the SWH with V-shaped plate absorber. This shows that the efficiency of the SWH with V-shaped plate absorber increased with 3.6-4.4% compared with that of the SWH with flat-plate absorber.

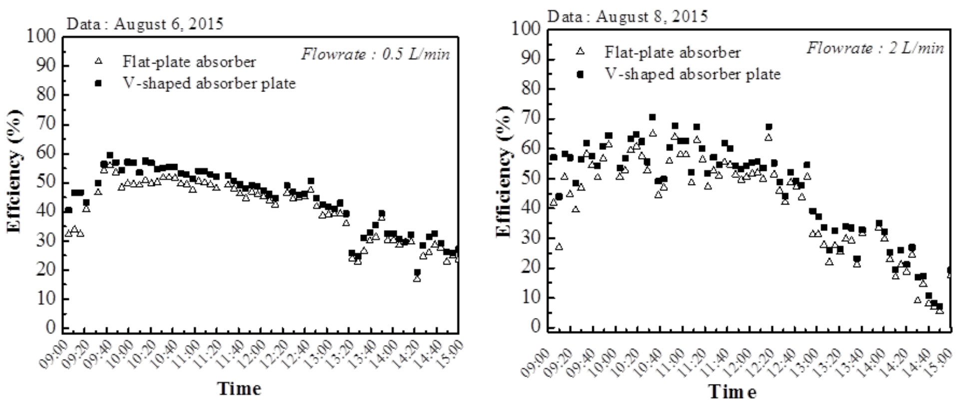


Figure 9 Collector efficiency of SWH system with flat-plate absorber and V-shaped plate absorber.

6 Conclusions

The absorptivity of a flat-plate absorber and various V-shaped plate absorbers was investigated. It was shown that the V-shaped plate absorber with an angle of $\beta = 21^o$ had better absorptivity compared with the flat-plate absorber and the other V-shaped plate absorbers. This type of V-shaped plate absorber was applied in the experimental study.

Two SWH systems with different absorber plates, i.e. a flat-plate and a V-shaped plate absorber, were investigated experimentally. The results showed that the SWH system with the V-shaped plate absorber had a better performance. Its efficiency was 3.6-4.4% higher compared with that of the system with the flat-plate absorber. Applying the V-shaped plate absorber in an SWH system increases its performance due to the increased absorptivity of its absorber plate.

Acknowledgements

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